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EFFECT OF CARBURIZATION, ON THE MECHANICAL PROPERTIES OF EN-8 STEEL IN DIFFERENT QUENCHING MEDIUM, AT DIFFERENT QUENCHING TIME INTERVALS.

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ABSTRACT

EN-8 is widely used for many general engineering applications. Typical applications include shafts, studs, bolts, connecting rods, screws, rollers. The Main Purpose of the Paper is to study the effect of heat treatment of carburizing specimens of EN-8(medium carbon steel) [1] by varying two parameter i.e. quenching time and quenching medium. The carburization process is carried out for 8 hours at a constant temperature of 940°C followed by quenching with different media like air, water and oil for various quenching times i.e. 60, 70 and 80 mins. The specimens so obtained are subjected to tests, for determination of tensile strength, Hardness and case depth. The results of these tests show that, as quenching time increases, there is an improvement in mechanical properties like tensile strength and are more for, water-quenched and least for air-quenched steels. Oil-quenched show intermediate values. From the experimentation, it is also clear that, as the depth of the carbon layer increases, hardness and tensile strength are also increasing. The experimental results are also supported by microstructure study, which show the formation of marten site, that causes improvement in hardness and tensile strength.

KEYWORDS: Medium Carbon Steels, EN-8, Carburization, Quenching Medium, Quenching Time, Hardness, Tensile Strength, Case depth & Microstructures

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Original Article

INTRODUCTION

Carburization provides a gradual change in carbon content volume from the surface to the core of a given steel sample, resulting in a gradual alteration of the mechanical and wear properties. The heat treatment and carburization enhances the mechanical properties. Carburizing is the addition of the carbon to the surface of the low, medium carbon steels at the temperatures generally between 850°C and 950°C, at which austenite is in stable crystal structure. Hardening is accomplished when the high-carbon surface layer is quenched to form martensite so that, a high carbon martensite case with good wear and fatigue resistance is superimposed on a tough, low-carbon steel core. Carburizing Steels for case hardening usually have base-carbon contents of about 0.2% with carbon content of the carburized layer generally being controlled between 0.8% - 1%C. However, Surface carbon is often limited to 0.9% because high carbon content can result in retained Austenite and brittle Martensite, which destabilizes the overall mechanical strength of the steel. In Order to achieve better Mechanical Properties in the Medium Carbon Steels (0.3%-0.6%C), the carbon content is increased by subjecting to a process called Hardening.

CASE HARDENING

Case Hardening is a simple method of hardening steel. Carbon is added to the outer surface of the steel, to a depth of approximately 0.03mm. This Hardening process includes a wide variety of techniques used to improve the mechanical properties and wear resistance of parts without affecting the softer, tough interior of the part.

Carburization [4]

It is a kind of case hardening where the chemistry of the surface needs to be changed by adding carbon and nitrogen to get hard martensite. This Category of treatment is called Chemical Heat Treatment and it involves nitriding, carburising, carbonitriding, cyaniding. Carburization, is simply defined as the addition of carbon to the surface of low/medium carbon steel, at a temperature between 850-950°C. It consists of enrichment of surface layers of medium carbon steel (0.3% - 0.6% C) to (0.8 – 1%), Carbon Content. By this way, the good wear and fatigue resistance is superimposed, on a tough medium carbon steel core. Usually, these steels have base carbon content as 0.35%, with the carbon content at the carburized layer, generally being controlled at 0.8-1% C. However, the carbon content is generally limited to 0.9% C, as to high carbon can result in retained austenite and brittle martensite [9].

OBJECTIVE

The Main Objective is, to improve the mechanical Properties of EN-8 medium carbon steel, by using acetone gas as a carburizer [2] and less energy consuming carburization technique. In this connection, the following steps were aimed to be carried out.

- Carburization of EN-8 samples under various conditions of carburization, by using less energy consuming techniques.
- Tempering of these carburized EN-8 samples at a definite temperature, for a particular period of time.
- Study of microstructure of the hardened steel samples.
- Determination of Mechanical properties, like Hardness and tensile strength of the carburized and tempered EN-8 Samples.
- Study of Carbon case depth of these carburized and tempered EN-8 samples.
- Analysis of the results obtained.

Mechanical Properties Studied

- Microstructure
- Case depth
- Tensile Strength
- Hardness

The effects of the following parameters on mechanical properties of carburized and tempered EN-8 samples, are also examined.

- Quenching Time
- Quenching Medium

The Inter Relation between different mechanical properties is observed.

METHODOLOGY

- **Selection of Specimen [3]:** The chemical composition of EN-8 by (wt %) is given as follows

Element	C	Mn	S	P	Ni	Si	Cu	Cr	Fe
Wt %	0.36%	0.32%	0.05%	0.2%	0.01%	0.03%	0.01%	0.01%	0.01%

- **Preparation of Test Specimens:** The test specimens for analysis of different mechanical properties like tensile strength, hardness, and case depth and grain structure are prepared as per British Standard and its description is given below.
- **Specimen for Microstructure Study:** The specimen for observing the microstructure is prepared by cutting pieces about ½ inch in height from the heat treated raw material rod. It is dipped in 2% Nital solution for 30 secs and dried, after which it is viewed under the microscope.

Figure 1: Sample Specimen for Observing Microstructure, Case Depth, Tensile Strength, Hardness.

- **Specimen for Case Depth Measurement:** The specimen of ½ inch height is taken from the heat treated area and grounded and polished. After washing and drying, it is etched with 2-4% Nital. Surface is then studied under tool maker's microscope.
- **Specimen for Tensile Strength Test:** A tensile test specimen as per British standard is prepared for the purpose, based on the following equation-

  $L_0/D_0= 5$

  L_0= Gauge Length

  D_0= Diameter

Figure 2: Sample Specimen for Tensile Strength Test

Hardness Test

Vickers hardness testing [7] is the method used for measuring the hardness of the EN-8 steel. Although hardness

testing does not give a direct measurement of any performance properties, hardness correlates with strength, wear resistance, and other properties.

Figure 3: Vickers Hardness Test

Tensile Test

The tensile strength is widely used to determine strength, ductility, resilence, toughness and several other mechanical properties. The Universal Testing machine is used to conduct tensile test on the EN-8 specimens.

Figure 4: Universal Testing Machine

Carburization of Steel Samples

The different test specimen samples made up of EN-8 steel for mechanical properties testing are subjected to carburization treatment. The EN-8 steel samples are carburized and then they are quenched in water, air and oil [11], i.e. the hardening is affected immediately after carburization. The carburized steel samples are then tempered for a particular temperature and time and then processed for different tests. By this carburization process the mechanical properties of tempered EN-8 steel samples have increased considerably [5].

RESULTS

The different kinds of EN-8 steel samples are carburized and tempered under the different conditions and the microstructure is analyzed and later tensile strength test, case depth test and hardness test are calculated.

Results of Microstructure Analysis

The microstructures of all the specimens were studied at both core and case regions were observed at suitable magnifications. The description of each microstructure is structured in Table 1.

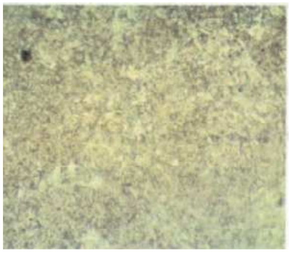


Figure 5.1(a): Microstructure of Core for Uncarburised EN-8

Figure 5.1(b): Microstructure of Case for Uncarburised EN-8

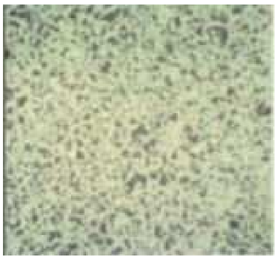


Figure 5.2(a): Microstructure of Core for Carburized EN-8 Quenched with air for 60 Minutes

Figure 5.2(b): Microstructure of case for carbirized EN-8 quenched with air for 60 minutes

Figure 5.3(a): Microstructure of Core for Carburized EN-8 Quenched with Air for 70 Minutes

Figure 5.3(b): Microstructure of Case for Carburized EN-8 Quenched with Air for 70 Minutes

Figure 5.4(a): Microstructure of Core for Carburized EN-8 Quenched with Air for 80 Minutes

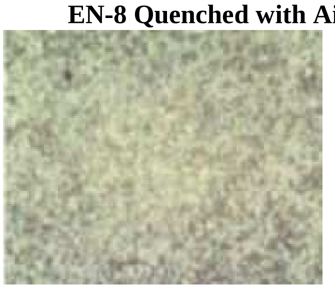


Figure 5.4(b): Microstructure of Case for Carburized EN-8 Quenched with Air for 80 Minutes

Figure 5.5(a): Microstructure of Core for Carburized EN-8 Quenched with Oil for 60 Minutes

Figure 5.5(b): Microstructure of Case for Carburized EN-8 Quenched with Oil for 60 Minutes

Figure 5.6(a): Microstructure of Core for Carburized EN-8 Quenched with Oil for 70 Minutes

Figure 5.6(b): Microstructure of Case for Carburized EN-8 Quenched with Oil for 70 Minutes

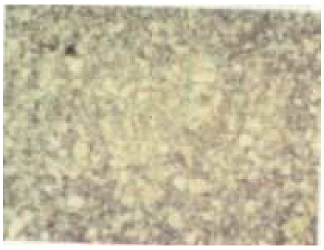


Figure 5.7(a): Microstructure of Core for Carburized EN-8 Quenched with Oil for 80 Minutes

Figure 5.7(b): Microstructure of Case for Carburized EN-8 Quenched with Oil for 80 Minutes

Figure 5.8(a): Microstructure of Core for Carburized EN-8 Quenched with Water for 60 Minutes

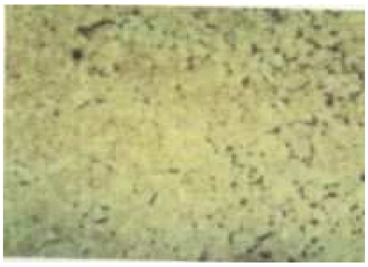


Figure 5.8(b): Microstructure of Case for Carburized EN-8 Quenched with Water for 60 Minutes

Figure 5.9(a): Microstructure of Core for Carburized EN-8 Quenched with Water for 70 Minutes

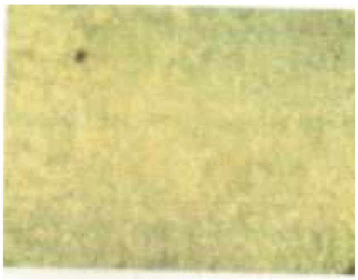


Figure 5.9(b): Microstructure of Case for Carburized EN-8 Quenched with Water for 70 Minutes

Figure 5.10(a): Microstructure of Core for Carburized EN-8 Quenched with Water for 80 Minutes

Figure 5.10(b): Microstructure of Case for Carburized EN-8 Quenched with Water for 80 Minutes

Table 5.1: Description of Microstructure[10]

Quenching Medium	Quenching Time	Remarks
Air	60 Minutes	**Case:** Abnormal Ferrite around the grain boundaries in matrix of Pearlite **Core:** 70% Ferrite,30% Pearlite
Air	70 Minutes	**Case:** Pearlite+Proeutectoid Ferrite outlining prior to austenite grain **Core:** 65% Ferrite,35% Pearlite
Air	80 Minutes	**Case:** Proeutectoid Ferrite outlining prior to austenite grain **Core:** 65% Ferrite,35% Pearlite
Water	60 Minutes	**Case:** Tempered Martensite in matrix **Core:** Ferrite and Pearlite in matrix
Water	70 Minutes	**Case:** Tempered Martensite in matrix **Core:** Ferrite and Martensite in matrix
Water	80 Minutes	**Case:** Tempered Martensite in matrix **Core:** Ferrite and Martensite in matrix
Oil	60 Minutes	**Case:** Martensite retained Austenite in the matrix **Core:** 45% Ferrite and 55% Martensite in matrix
Oil	70 Minutes	**Case:** Fine tempered Martensite in the matrix **Core:** Tempered Martensite in the matrix
Oil	80 Minutes	**Case:** Coarse Martensite in the matrix **Core:** Tempered Martensite in the matrix

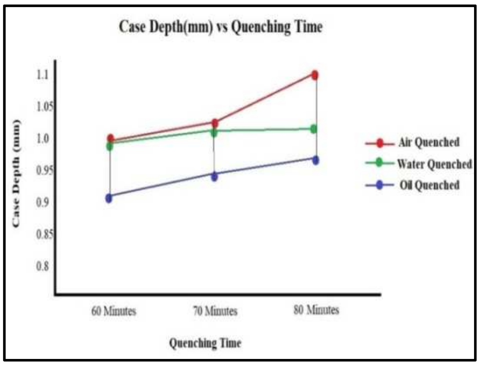
Results of Case Depth

The results of the case depth measurement test, for different carburization conditions are tabulated and are shown in Table 5.2. Plots showing the variation in case depth, with respect to each input parameter are shown in Graphs 5.1 & 5.2.

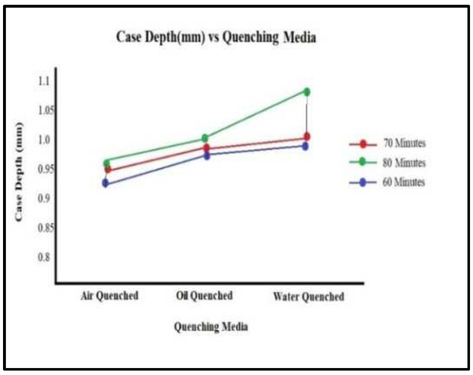
It can be observed that, the case depth increases with increase in quenching time, when the medium is similar. Also, for a given quenching time, the case depth is highest for water followed by oil and then air.

Table 5.2: Case Depth for different Quenching Media and Time

Quenching Medium	Quenching Time (min)	Case Depth(mm)			
		Measurement 1	Measurement 2	Measurement 3	Average
Air	60	0.91	0.933	0.915	0.919
Air	70	0.93	0.94	0.95	0.94
Air	80	0.957	0.95	0.97	0.959
Oil	60	0.991	0.989	0.981	0.987
Oil	70	0.995	0.987	0.997	0.993
Oil	80	1.011	0.007	1.012	1.01
Water	60	0.991	1.003	0.997	0.998
Water	70	1.01	0.99	1.027	1.012
Water	80	1.03	1.12	1.09	1.08



Graph 5.1: Case Depth vs. Quenching Time for various Quenching media



Graph 5.2: Case Depth vs. Quenching media for various Quenching time

Results of Tensile Tests

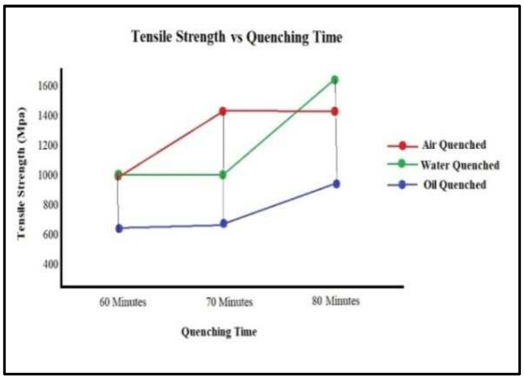
The Heat treatment and Carburization of EN-8s resulted in an increase in hardness. Tensile strength and wear resistance and decreased the weight loss during abrasion and toughness values. The tests results of different mechanical characteristics like tensile strength and hardness under the different carburization conditions arc shown in Table 5.3,5.4 and 5.5 and summarized the following points.

- The tensile strength is varied between the ranges of 650 MPa — 1650 MPa (Table 5.3)[6] and is highest for the steel carburized for 8 hours, followed by Water Quenching for 80 Minutes and lowest for the steel carburized for 8 hours, followed by Air Quenching for 60 Minutes, so with increase of quenching time the tensile strength increases. This is also shown graphically in the Graph 5.3 & Graph 5.4. This result shows that, the carburization improved the tensile strength of EN-8.
- The hardness values varied between range of 296 HV to 765.33 HV (Table 5.4 and 5.5) and it is highest for the EN-8 steel Quenched for 80 Minutes in water and is lowest for the EN-8 steel Quenched for 60 Minutes in air, so with increase of quenching time the hardness values increase. This is also shown graphically in the Graph 5.5 & Graph 5.6.
- The Tensile Strength values are directly proportional to the Hardness values. As the Hardness values increases, the Tensile strength also increases. This is also graphically shown Graph 5.7.

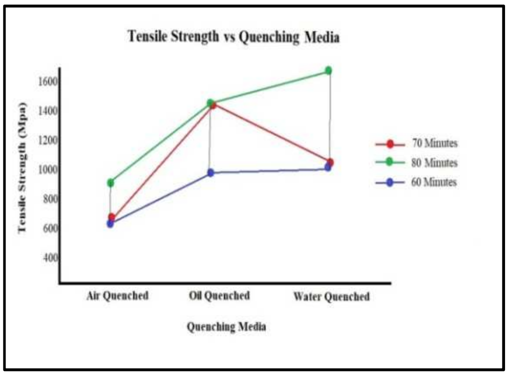
Finally the Net result is that the EN-8 Steel quenched for 80 minutes in Water medium is giving the best results for the mechanical and wear properties like Tensile strength and Hardness [8].

Table 5.3: Tensile Strength for different Quenching Media and Time

Quenching Medium	Quenching Time (min)	Tensile Strength(Mpa)
Air	60	656.958
Air	70	675.805
Air	80	910.64
Oil	60	962.218
Oil	70	1363.856
Oil	80	1421.98
Water	60	983.29
Water	70	997.12
Water	80	1649.172



Graph 5.3: Tensile Strength vs. Quenching for various Quenching Media



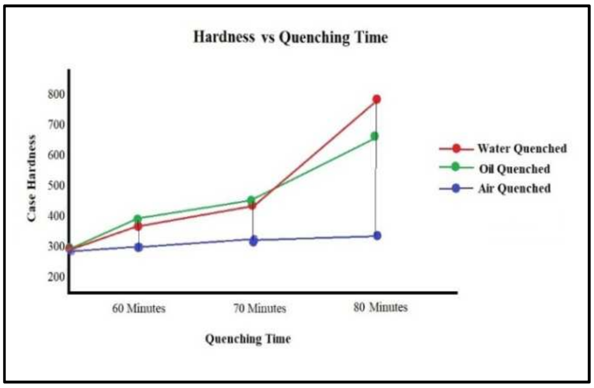
Graph 5.4: Tensile Strength vs. Quenching Time Media for various Quenching Time

Table 5.4: Case Hardness Values for different Quenching Media and Time

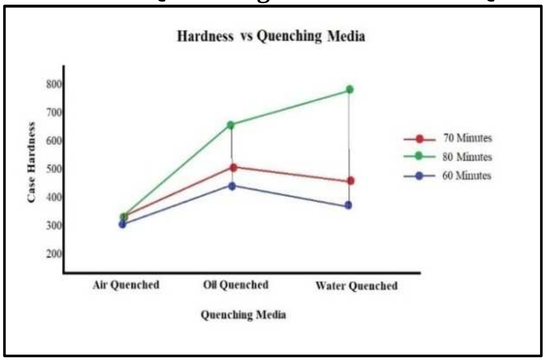
Quenching Medium	Quenching Time (min)	Case Hardness			
		Impression 1	Impression 2	Impression 3	Average
Air	60	297	294	297	296
Air	70	322	319	319	320
Air	80	327	325	327	326.33
Oil	60	429	425	429	427.33
Oil	70	498	493	498	496.33
Oil	80	657	649	649	651.33
Water	60	390	390	387	389
Water	70	498	464	498	466.67
Water	80	772	762	762	765.33

Table 5.5: Core Hardness Values for different Quenching Media and Time

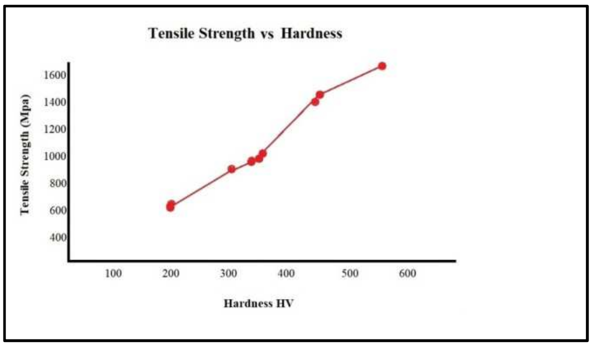
Quenching Medium	Quenching Time (min)	Core Hardness			
		Impression 1	Impression 2	Impression 3	Average
Air	60	159	160	159	159.33
Air	70	147	146	147	146.67
Air	80	264	262	264	263.33
Oil	60	212	210	212	211.33
Oil	70	387	383	383	384.33
Oil	80	227	225	225	225.67
Water	60	254	256	254	254.67
Water	70	193	194	193	193.33
Water	80	354	253	254	287



Graph 5.5: Hardness vs. Quenching Time for various Quenching media



Graph 5.6: Hardness vs. Quenching Media for various Quenching time



Graph 5.7: Tensile Strength vs. Hardness

CONCLUSIONS

From the present studies on "Effect of Carburization on the Mechanical Properties of EN-8 by varying the Quenching Medium and Quenching Time" - the following conclusion have been drawn.

- The mechanical properties of EN-8 were found to be strongly influenced by the process of carburization.
- 2. The carburization treatment followed by the quenching appreciably improved the hardness and tensile strength of EN-8s.
- 3. Hardness, case depth and tensile strength increased with increase in the quenching time.
- 4. The quenching medium also deeply affected the mechanical properties of EN-8
- 5. For a given quenching time, hardness, case depth and tensile strength are more, for water-quenched and least for air-quenched steels. Oil-quenched show intermediate values.
- 6. As comparing for different quenching times, The EN-8 quenched for 80 minutes shows the best combination of higher hardness, higher tensile strength.
- 7. As comparing for different quenching media, The EN-8 quenched in water medium, shows the best combination of higher hardness, higher tensile strength.
- 8. Finally the net conclusion is that the EN-8 carburized and quenched under the different quenching media air, water and oil, quenching time for 60, 70, 80 minutes, with in which the best results for the mechanical and wear properties like tensile strength, hardness were given by 80 minutes water quenched EN-8.

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